Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE
JOURNAL OF GEOLOGY

MAY-JUNE, 1908

FEATURES INDICATIVE OF PHYSIOGRAPHIC CONDITIONS PREVAILING AT THE TIME OF THE TRAP EXTRUSIONS IN NEW JERSEY

C. N. FENNER

The Watchung Mountains form prominent features in the topography of Northern New Jersey. On account of the great hardness and erosion-resisting qualities of the rocks composing them, they rise well above the surrounding shales and sandstones and add much to the beauty and picturesqueness of this portion of the state.

Their geological features and their relation to the adjacent strata have been the subject of study since the early years of the last century. Views regarding them have changed greatly. New facts have been brought to light and the interpretation of the observed conditions has changed with the advance of geological science. Gradually, however, a close agreement has been reached in the conclusions of various observers with regard to the major features of their structure and relations, and in brief form it may be said to be held that these three ridges are the remnants of three successive flows of lava which were poured out as great sheets over the surface of beds of sandstone, or similar material, which was in course of deposition at the time. After each flow the process of deposition of the sandstones was resumed until interrupted by the next flow. Later the whole series of sandstones and intercalated traps was slightly tilted so as to form a monocline with gentle western dips, and the edges were eroded and carried away. The trap sheets, on account of their resistant qualities, were less degraded, so that now their projecting edges form the ridges of the Watchung Mountains.

In this article it is my purpose to describe certain facts of observation which have been met with in studying this region, especially that portion of it lying in the territory of the First Watchung trap from Paterson southward, and which may throw some additional light upon the relations of the traps and underlying sandstones and upon the general physiographic conditions which existed at the time of their formation. Quarrying operations of recent years have brought certain features to light which are of importance in their bearing upon this subject.

In order to lay a proper foundation for the facts which are about to be described and to show their significance, it is necessary to enter into some description of the underlying clastic formations.

THE CLASTICS

The lowest trap sheet (the First Watchung Trap) rests everywhere upon a series of siliceous stratified rocks. On account of the paucity of fossils contained in these associated strata and the somewhat uncertain position in the paleontological succession of the fossils which have been found, the exact horizon of these rocks is somewhat uncertain. They are generally regarded as being of Triassic Age, but it is preferable to use the indefinite term, "the Newark Formation," in referring to them, as is done by the United States Geological Survey, until more exact correlation can be established. In this article it is my intention to consider in detail only those members of the Newark Formation which are found in immediate association with the base of the First Watchung Trap, and to study these chiefly for the purpose of determining the conditions existing at the period when the trap sheet was poured forth. The rocks of the Newark Formation as a whole are of interest in this connection in forming general conclusions with regard to these conditions; but there is the possibility of undiscovered faults running through the series, which might throw altogether out of concordance the strata on the two sides of the break, and vitiate the value of the conclusions drawn. Therefore in endeavoring to arrive at a proper conception of the conditions immediately preceding the trap-flow, it is better to confine our studies to the territory closely adjacent to the trap itself, using in addition only such conclusions as apply to the Newark Formation as a whole.

At one time, before a detailed study of the region had been made and before the present advance of geology, a submarine origin was assigned to the Newark beds. Later the impossibility of their deposition under such conditions was perceived and it was suggested that they were laid down in an estuary or on the bed of a great river. This theory is still quite commonly held, but many later observers have come to the conclusion that they are almost wholly of continental origin. By this it is meant that they were laid down on land surfaces standing at some elevation above sea-level, on which bodies of standing water, such as lakes or pools, formed but a minor factor so far as sorting of material and deposition of sediments were involved. The conditions must be conceived to have been similar to those now present in the semi-arid inland basins of the West. The chief agencies of transportation and deposition were the general creep of waste material down slopes from disintegrating areas of older rocks in the high lands, the rush of torrential streams, the flow of rivers of more or less permanence, and the sweep of winds. In the lowest portions of the troughs of deposition there would naturally be shallow lakes, unless conditions of extreme aridity prevailed, and I will endeavor to show later that such lakes were probably present in the area under discussion at the time of the overflow of the trap.

In connection with the theory of a continental origin for these deposits we may quote W. M. Davis on the similar area in Connecticut:

> There is little or no direct evidence for marine deposition of the Connecticut Trias. There are no marine fossils yet found. The fish whose imprints occur plentifully in certain occasional strata of black shale are allied to fresh- or brackish-water forms. The prints of land plants and the tracks of land animals argue against the presence of the sea. The tidal currents that have been assumed to be necessary to carry the materials found in some of the coarser layers may be replaced by other agencies that can as well accomplish this result over the moderate distances here involved. If marine at all, the waters must have been littoral and shallow, and the bottom must have been frequently bared to the sun.[1]

These remarks are equally applicable to the New Jersey area.

Let us now examine the clastic deposits immediately underlying the Watchung traps and ascertain to what extent their structure bears out the theory of continental origin. We find that they form a monotonous series of shales, sandstones and conglomerates, composed mostly of quartz fragments. Sufficient oxide of iron is usually present to give a reddish, brownish, or purplish color to the whole. Feldspathic material is often visible, and the derivation of all these is plainly referable to the crystalline areas on the East or West. In addition to these we find in many of the coarser layers plentiful pebbles of limestone, up to six inches or more in diameter, whose source is obscure.

---

[1] *Tenth Annual Report* U. S. Geological Survey, Part II, p. 32.

In observing carefully the succession of strata in this series one is at once impressed with the lack of continuance of the beds in any direction and the variation in the succession at different sections along the same horizon. Within a distance of a few hundred feet the character of the section may change markedly. This may be brought about in three ways.

1. A bed may gradually thin out and disappear. This is especially true of the sandstones.

2. The size of the fragmental material may alter in a pronounced manner, while the thickness of the stratum remains approximately the same. The proportion of pebbles in a bed of sandstone or even of shale may increase or diminish rapidly. This is generally brought about, however, by the intercalation of pebble beds in the sandstone layers, rather than by a general increase in the coarseness of all the material.

3. A given stratum may be cut sharply away, and different material abut against it.

All these variations are shown in the gorge of the Passaic River, a short distance below the falls at Paterson. Fig. 1 is from a sketch made just south of Ryle Avenue. Two very irregular bands of shale (*a* and *b*) cut sharply downward across the sandstone and pebble beds, and are overlain by strata differing from those in the same horizontal planes on the right. It appears evident that a water-course has cut its way through previously deposited strata, and the valley thus formed has later been filled by water-borne sediments or wind-blown sands until a level was again reached and a more orderly course of deposition was continued across it. The pot-hole at (*c*) filled with gravel, stones, and shaley material, is instructive in this connection. Following these bluffs southward about 350 feet we come to the southern side of the same river-valley, as shown in Fig. 2. We find there, as we should expect, that while the line of the bank is shown by the same downward sweep of the strata, the succession of deposition is quite different from that shown in Fig. 1, indicating a desert stream which at times may have spread over the whole width of its course, and again dwindled to a rivulet or become dry. It is noticeable that the trap-sheet above also bends downward at this point, showing that a shallow depression still existed here when the lava stream covered the whole.

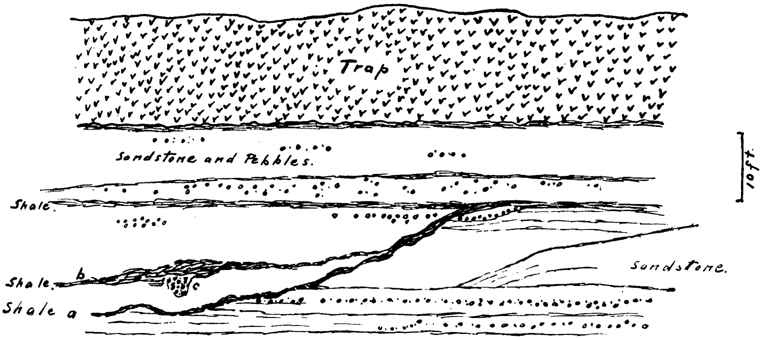


Fig. 1.

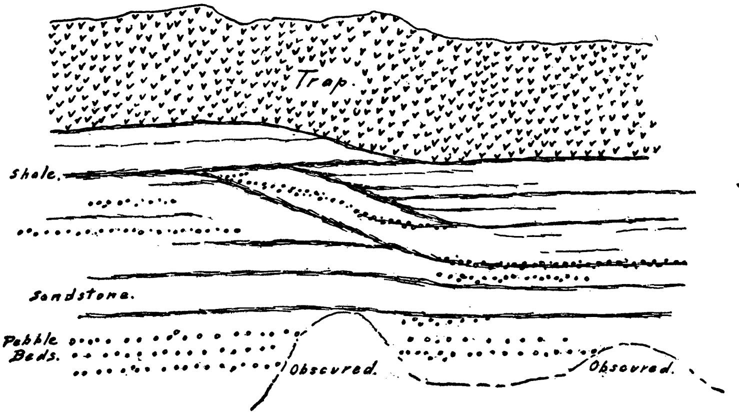


Fig. 2.

Another example of variations in strata is shown in Fig. 3, a section at Pope's old quarry, near Garret Rock. This is a sketch of the west face, north end of quarry. Marked variations of the strata show themselves along the quarry face, and the section shows no resemblance to any part of Fig. 1 or Fig. 2, though less than a mile distant and at the same horizon (just beneath the trap sheet).

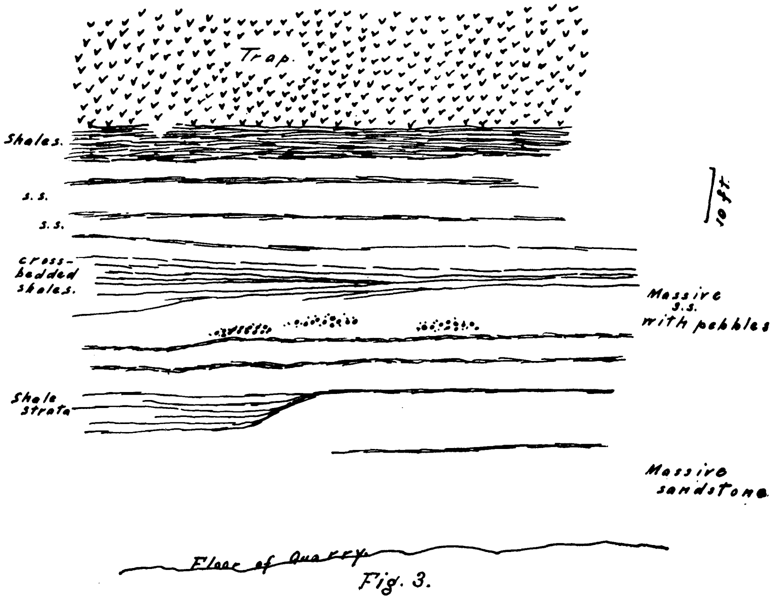


Fig. 3.

At Thomas' quarry at Albion Place there is an instance of the complete thinning-out and disappearance of a sandstone bed, probably five feet thick at its maximum. This is at the northern end. High up on the western wall a massive bed of sandstone has several feet of its upper part cut sharply away at one place, and shales abut against it.

These examples show the great tendency of the strata to vary in a large way, and are inconsistent with any form of marine deposition, or of any theory of deposition which does not take cognizance of sharp changes within small areas. When we take up the consideration of smaller details of structure we are met again with proofs of this same tendency to variation, as is shown by a study of the smaller features of the shale, sandstone, and conglomerate beds.

THE SHALES

These are well described by the term "ferruginous silicilutytes" of Professor Grabau's classification; that is, they are finely-comminuted siliceous material, strongly impregnated with oxide of iron. Their laminations may be paper-like in thinness but are generally coarser. On exposure to the weather they break up into a multitude of crumbly fragments. Mica scales are very plentiful. The surfaces of the laminae frequently show a multitude of irregular markings—grooves, pits, curved lines, lumps, smooth patches of irregular shape, etc., not all of which can be deciphered with any certainty. Many, however, can be identified. Mud-cracks, rain-pits, and worm-grooves are frequent. Rill-marks are sometimes found. At times films of impalpable sediment are found in the depressions in the lumpy surfaces of certain sandstone layers, which, in their delicate markings, suggest irresistibly the frothy scum left in hollows after a rain. Again thin curled layers of shale appear plentifully in the midst of sandstone. The effect is precisely that which would be produced by a layer of mud, drying and curling at the edges, being buried by a deposit of wind-blown sand. The layers of mud are too fragile to permit the supposition that the sand was carried by currents of water. Other examples show plentiful flakes of shale mixed with sand, the occurrence being apparently due to a mixture of material produced by the wind. I have seen wave-marks in the shales and have found them also in the finer sandstones. In the latter too I have found one very distinct print of an apparently three-toed reptile. The impression is a trifle over an inch in width and on one side is an irregular, curved groove, probably made by the animal's tail. In the fine shales there are many impressions which suggest the marks which would be made by living creatures moving about in soft mud. They are too uncertain, however, to offer more than a suggestion. In other localities, as in the Connecticut valley and other parts of New Jersey, many reptile trails have been found, but those spoken of here were found in the territory under discussion in material taken from a short distance below the trap sheet, and serve as an index of conditions just preceding the flow.

These shales are to be regarded as muds deposited in lakes, rivers, or pools. The markings described owe their preservation to the retreat of the waters and the baking of the mud under a hot sun. That arid conditions prevailed is indicated also by the frequent presence of sharply defined pieces of shale in the pebble beds. During long exposure the iron-impregnated mud must have hardened to such a degree as not to be ground up and destroyed by a succeeding rush of torrential waters.

THE SANDSTONES

These are ferruginous silicarenytes—siliceous sands, colored by oxide of iron. In places they form extremely massive beds in the series, up to 25 or 30 feet in thickness, with hardly a line of parting. Beds of this kind are made up of rather coarse quartz fragments, rounded or subangular, mixed with a little decomposed feldspar, and frequently show no hint of stratification on either fresh or weathered surfaces. The finer sandstones carry much mica and are generally better stratified. A little cross-bedding has been observed, the direction of the lines differing by a slight angle.

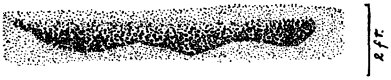


Fig. 4

The sandstone strata may contain anywhere in their mass individual pebbles or small beds of pebbles of irregular shape and extent.

Fig. 4 shows a characteristic pebble bed on the west side of Thomas' quarry. Pebbles are up to one-half inch or more in diameter. Below is even-grained sandstone separated by a sharp line from the pebbles. Above, the gravel grades into sandstone. Fig. 5 represents the structure of a gravel bed a few hundred feet north of the D. L. & W. R. R. station at Paterson. On the left side the dividing line between gravel beds and sandstone cuts sharply downward across the sandstone layer. On the right there is a grading of pebbles into sand. A rough stratification is apparent in the pebbles. Fig. 6, from Pope's quarry, illustrates a somewhat different feature. The intercalated bed is here mostly shale, in the midst of a massive sandstone.

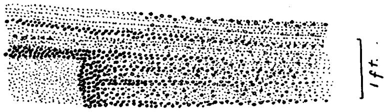


Fig. 5

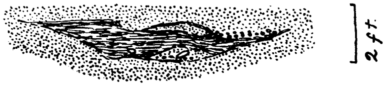


Fig. 6.

These are by no means isolated occurrences, but are repeated in a similar fashion in innumerable exposures. The obvious explanation is that they represent the channels of small streams which cut across the face of the country. The sandstones in which they occur I would refer to an aeolian origin, and believe them to have formed the surface of the ground at the time the streams cut their channels. By this I would not be understood to imply that water played no part in the transportation of the sand grains from their original homes in the crystallines. They may have been picked up and laid down repeatedly, now by wind and again by water, before reaching their final resting place, and it would be impossible to draw a sharp line and say that here the work of water ceased and here the work of the wind began. Their final attitude, however, is to be attributed chiefly to the action of the wind. The fact of the subaerial accumulation of the great masses of sandstone should be emphasized, for their freedom from moisture at the time of the trap flow has an important bearing upon certain structural features of the trap.

At Little Falls, a few miles west of Paterson, a bed of sandstone lying about fifteen feet below the second Watchung sheet, carries abundant plant impressions. The remains of woody stems are found which have been converted into coal, and twigs and leaves have also left their impressions in the stone. From the completeness of the forms preserved the trees were evidently not carried to this point from a distance and I am inclined to believe that this is actually the site upon which they grew. Although not in the area under discussion, this occurrence is interesting as indicating the continuation of continental conditions up to the time that the second flow of trap spread over the region.

THE CONGLOMERATES

Everywhere throughout the sandstone strata pebble beds similar to those described are of frequent occurrence. Even the shales may contain locally a large amount of gravel. In addition to these, heavy beds of coarse conglomerate are sometimes seen, though they are not as frequent as the sandstones and shales. They were exposed a number of years ago a little to the southeast of the Great Notch in a trench dug for a water-supply system, and at the present time are especially well seen in the sandstone quarry in the gorge of the Passaic, on the eastern side of the river. The conglomerates here carry quantities of shale mixed with the gravel. The old streams, of which these are the beds, evidently deposited at times quantities of mud. As the waters ceased flowing the mud was dried and baked till it became well hardened. When the next rush of waters came some of the strata of hardened mud withstood the force of the stream, but others were broken up and the pieces mixed with the pebbles and swept along with the current. From the recurrence of the phenomena this must have happened time and again.

The pebbles of the beds are mostly quartz, sometimes only slightly rounded. Limestone is also of frequent occurrence.[1] Often weathered surfaces of the conglomerate show rounded cavities from which limestone pebbles have been dissolved, and the general porosity of the beds may be partly due to the solution of smaller lime grains. The presence of these limestone pebbles indicates a not distant source, but nothing from which they could have been derived is to be found for many miles. The original strata were either totally broken up and carried away or, more probably, were buried beneath later deposits.

It is to be noted that the pebbles are all of moderate size, rarely more than six inches in diameter. No bowlder masses, like those which are common in river channels, ancient and modern, in regions of rugged relief, are to be found here. The trough of depression, in which deposition was proceeding, had been filled so that the surface of the buried valley was now almost a level plain, on which the rush of waters, even from torrential streams, soon lost its force.

From the evidence of the rocks themselves at the base of the First Watchung Trap we are able to picture, with a fair amount of certainty, the character of the region and the conditions of the deposition of strata preceding the period of the lava flow. We see on the east and the west chains of hills of moderate relief, composed of the old crystalline rocks, whose surfaces gradually disintegrated under the effects of the weather, and the detritus from which was carried down the slopes and spread over the intervening valley. The climate was arid,

[1] In a couple of pebbles of decomposed limestone which I found in these conglomerates there were abundant fossils. Crinoid segments were very numerous, and bryozoans were abundant. There was also a fragment which may have been the pygidium of a trilobite.

and during the long periods of drought the streams dwindled away or sank into the sands. At times, however, torrential storms or cloudbursts occurred and the sudden rush of waters carried heavy loads of waste material before them. In the dry periods strong winds played an important part. They gathered up every exposed grain of moderate size from the higher ground, and swept it into the valley and spread it out in accumulations which reached great thickness.

The floor of the valley was almost flat, or at most had a gentle slope away from the mountains toward the axis. In the lower-lying portions lay one or more shallow lakes, which in periods of comparatively large rainfall spread over wide expanses, and in dry periods contracted within narrow limits.

THE LAVA FLOW

Over such a region as we have pictured a great lava flow was suddenly poured forth. The points at which extrusion took place are uncertain. There seem to have been no preliminary phenomena such as often precede lava flows. No deposits of tuff or other ejectamenta, indicative of explosive violence, are found in this region. The lava seems to have quietly welled forth and, as we shall see later, spread out in a thick sheet in a flow which was practically continuous.

From whatever point the flow may have entered the region its natural course would be along the trough of the valley. The shallow inequalities which existed in the surface offered no serious obstacle to it; the fluid lava filled them and passed on. Such small bodies of water as were encountered were perhaps quickly turned to vapor and driven off. Nevertheless the lakes have left their record upon the molten rock, and though in places the writing has become dim with the lapse of ages, it has proved so nearly indestructible that it can still be deciphered, and the site of the lake beds, and hence the line of central depression of the valley, can be determined with a fair degree of confidence. If we are not able to do this throughout the area, it is because the field has not yet been thoroughly studied with this object in view, or because the structure of the trap is not sufficiently revealed in the surface exposures.

The process of reasoning is as follows: Where the lava covered arid soil it was practically unaffected by water. The air and the trace of water contained in the interstices of the ground would be expanded by the heat, and having no other escape would force themselves into the molten lava and render it vesicular for a short distance above the contact, but the great mass of lava would be left dense and unaltered. At the surface of the sheet the escape of occluded gases might also produce a slightly porous structure. But where the lava poured over lake beds the case was different. The standing water was probably not of sufficient volume to produce much effect, but the underlying strata were thoroughly saturated. The heat of the lava penetrated downward slowly but irresistibly, and the water was vaporized. If there had been no means of escape, the pressure would have gone on accumulating until it became enormous, but before this the vapor began to push itself up through the over-lying lava, and thus found vent. It continued thus to force its way long after the lava congealed, and finally the temperature dropped to such a degree that currents of heated water replaced the steam. The effects produced constitute the record left and will be described in detail.

Let us first, however, examine the structure of the trap in its less affected portions. The gorge of the Passaic in the vicinity of Figs. 1 and 2 offers good opportunities for this. It is seen that the contact is practically conformable with the stratification of the underlying sandstone series, but there are slight irregularities, and at the point where Fig. 2 was sketched the trap drops about six feet. For a short distance above the contact, that is, from a few inches up to four or five feet, the trap is vesicular. Above this it is firm and dense to the top of the cliff. At Garret Rock there is another good exposure of the contact where the D. L. & W. R. R. rounds the point of the mountain. The contact is perfectly sharp, but slightly irregular. There is no mixture of the trap and sandstone. The vesicularity of the trap extends about three feet up and the sandstone also shows small passages through which gases were forced. Fig. 7 shows a typical example of the contact here. In some places the trap is so welded to the sandstone that the same hand specimen will show both.

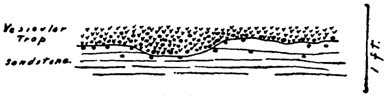


Fig. 7.

At the trap quarry southwest of Albion Place there are certain features of interest. At the contact there is a mixture of vesicular, decomposed trap, and lumps of hardened mud. The whole is much affected by weathering, but it is easy to distinguish between the igneous and sedimentary material. This mixture forms an irregular band about six inches in width. Below is red shale, not perceptibly altered, extending downward for several feet. Above the mixed band, the trap is vesicular for a few inches, and passes upward into fine-grained, dense rock. The impression produced is that the first thin stream of advancing lava flowed over a bed of rather damp mud and became mixed with it, and that this in turn was soon covered by later streams.

In this quarry for one hundred feet or so along the quarry face, about six feet above the contact, there is a band of trap, two or three feet in width, having the structure shown in Fig. 8. The lines of the sketch represent cracks from one-half inch wide down to a mere seam, which extend approximately horizontally along the cliff face and back into the rock, and permit it to be separated easily into slabs. The cracks are filled with a loose, granular material, generally of a dark color, but showing calcite grains in places. This same slab-like or platy structure can be observed as of frequent occurrence in the more massive portions of the trap sheet in various localities, though seldom so well developed as here. It is a fair inference that these plates represent rivulets of lava, and that the chilled surfaces have been more easily weathered. The advance of the lava flow should not be pictured as similar to that of a sheet of water. On account of viscosity and partial congelation, the spreading out of a sheet of even the most fluid lava is quite a different process. We should picture the advance of this Watchung sheet as similar to the form of the Hawaiian lava flows described by Major Dutton:

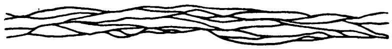


Fig. 8.

> When these lavas are discharged they come up out of the ground in enormous volumes, are intensely heated, and are very liquid. . . . . As they become cooler they become more viscous. The cooling takes place upon the surface of the mass while the interior still remains hot and preserves a viscous liquidity. The superficial crust of cooled lava undergoes rupture at numberless points, and little rivulets of lava are shot out under pressure. Preserving their liquidity for a short time, they spread out very thin and are quickly cooled, forming pahoehoe. Scarcely is one of these little offshoots of lava cooled when it is overflowed by another and similar one, and this process is repeated over and over again. In a

word pahoehoe is formed by small offshoots of very hot and highly liquid lava from the main stream, driven out laterally or in advance of it in a succession of small belches. These spread out very thin, cool quickly, and attain a stable form before they are covered by succeeding belches of the same sort.[1]

Above the reticulated strip described comes fifteen feet of nearly massive trap with few joints or planes of separation, and above this, along an irregular line, there is a blocky variety of considerable thickness. Except for the narrow band of vesicular trap on the contact the texture of the whole mass is firm and dense and the rock is of flint-like hardness.

We may continue southward for several miles along the cliffs marking the eastern face of the mountain, and find almost identical conditions everywhere. The base of the trap sheet shows slight irregularities but is practically conformable with the bedding of the sandstones and shales. For a short distance above it is apt to be somewhat porous, but the great upper mass is perfectly dense.

Evidence of the existence of a lake bed, covered by the lava flow.—Let us now follow the D. L. & W. R. R. westward from Garret Rock to the West Paterson trap quarry. Garret Rock is a bold cliff marking the eastward scarp of the mountain, and from here the railroad makes a section almost at right angles to the line of the ridge. About three thousand feet from the rock it passes the quarry mentioned, which is in the very midst of the trap area. The quarry has been famous to mineralogists for years for the specimens of zeolites and associated minerals which have been obtained from it. It is only within about a year, however, that operations have proceeded so far that the geological conditions have become plain and the whole story revealed so that it can be easily read. The section is so perfect, and the rock and its minerals are so fresh and unaltered that a careful study of the exposure should be made. We shall find here the explanation of features occurring elsewhere, which by themselves might convey little meaning.

The first observation which will probably be made is that here in the midst of the trap area the bottom of the quarry shows a floor of hardened red mud rising from the west toward the east. On this the trap rests. Along the contact for a width of ten feet or more the trap and mud show evidences of having experienced the most violent agitation. The two are mixed and kneaded in a manner so involved that it can hardly be imagined. The mud has boiled through and through the seething body of lava until particles of mud of every size from minute specks to large masses have become incorporated in the pasty flow. Both lava and mud are full of blow holes, steam vents, and other forms of irregular pipes and cavities which attest the violent escape of gases.

---

[1] *Fourth Annual Report,* U. S. Geological Survey, pp. 95, 96.

Above this confused mixture the lava is generally found to show a transition to a purer condition. It is still thoroughly vesicular for several feet, but less mud is found in it as we go upward. Still higher no mud whatever is found, and the overlying mass of lava, probably nearly seventy-five feet in thickness to the surface, is purely igneous rock. The structure of this, however, is very different from the close-textured rock which we found along the eastern border of the trap sheet; and, in its way, the evidence of the action of escaping gases and heated waters is as perfect as in the underlying portions. Amygdules are still frequent, but the more characteristic appearance is the bowlder-like structure shown in Fig. 9. The bowlders are of dense trap, with crusts of dark glass. Vugs of mineral lie between, and it is in these vugs that the crystallized zeolites are found.

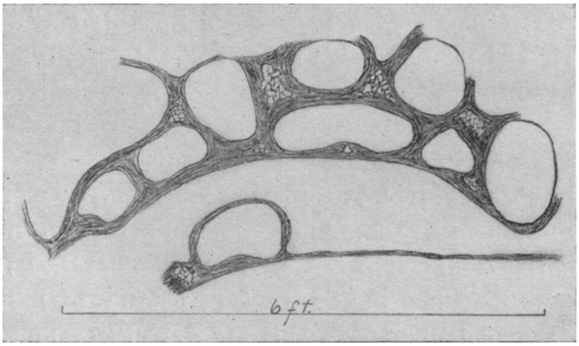


FIG. 9

This structure is common throughout the whole quarry. Even the masses of trap which do not show the glassy crusts or the vugs are so seamed with fissures as to be easily broken apart. Toward the surface of the ground this structure is not so evident. This is mostly due, no doubt, to the leaching-out of the secondary minerals, but the impression is left that in its original occurrence it may not have been so well developed in the upper layers.

The course of events which gave rise to these features is to be explained as follows: Before the lava flow occurred this site was occupied by a shallow body of water with a muddy bottom. When the first thin flow of intensely heated igneous rock plunged into it, the violent agitation resulted in a thorough mixture of the two. At short intervals further flows added to the depth of the mass. The successive spurts and tongues of fused material burst forth everywhere. Chilled almost at once by the steam pouring around them, they built up a structure of bowlder-like forms. The original body of water was quickly driven off, but that contained in the saturated strata beneath was changed to steam and rushed up through the mass. Some of it found its way into and through the fused material, but the greater part worked its way around and among the bowlders, with the result of quickly cooling the crusts, producing a glassy texture and a multitude of cracks. The evidence of these effects throughout the seventy or eighty feet to the surface indicates that at least this depth of lava had reached its position while the action was still continuing, though it does not follow that there may not have been intervals during which the flow of lava ceased.

Further than the physical effects of chilling the lava and producing the crusts and cracks, the steam seems to have had little result. In places the inner surfaces of the blow-holes have no lining of minerals but appear entirely unaltered. In another locality, which will be described later, many of the steam vents were blown full of sand or dust and this frequently lies up against the chilled glass, without any indication of alteration in the latter. Later, after a considerable interval of time, the mass of lava cooled to such a degree that the underlying reservoirs began to supply a mixture of water with the steam, and finally merely heated waters passed up through the vents, and with these the crystallizing action and formation of minerals began. The lava had been so thoroughly seamed and cracked that it could not have offered much obstruction to the flow of these waters, and it does not seem that they could have been at any time under a pressure which would greatly raise their boiling point. Rather must we suppose that the principal mineralizing effects were due to waters having a temperature but little above 100° C.

Further evidence of a relatively unobstructed and rapid circulation of water is supplied in the fact that frequently the transparent crystals lining the vugs show inclusions of dark sediment, or again the crust of perfectly formed crystals is covered with a deposit of the same sedimentary material.

The minerals produced are largely due to the action of these hot waters upon the glassy crusts of rapidly chilled trap. The muds themselves show practically no alteration except hardening, and the elements of the minerals are those of the igneous rock, with water added. In fact the zeolites seem to be the direct result of the addition of water of crystallization to the albite and anorthite mixtures of the feldspars and result from a crystallization of previously existing silicate material by a slight modification of its composition. The presence of datolite and apophyllite—compounds carrying boron and fluorine—indicates that the elimination of magmatic vapors from the igneous material was still in progress during the process of formation of the secondary minerals. Such emanations may have been powerful agents in conveying to the channels of circulation material derived from the magma, and in the rearrangement of the various elements present.

All stages of transition in the alteration of the trap and the formation of minerals from it are common. Frequently we find a breccia with angular fragments of trap as nuclei and crystalline minerals for a filling. The most perfect crystals, however, form linings to the cavities between the bowlders. I believe there is evidence of a definite sequence in the formation of the minerals but there are difficulties in determining it in many cases. Apparently, however, it is as follows: First, a dark green, chloritic mineral, followed by prehnite, datolite, and pectolite; then the zeolites, analcite, laumontite, chabazite, natrolite, heulandite and stilbite; ending with apophyllite and thaumasite. Quartz and calcite are very common but seem to have been deposited at several stages and cannot be assigned a definite position in the series. The only metallic minerals observed are chalcopyrite and hematite. Small grains of these, sometimes well crystallized, are common, but like quartz and calcite, they cannot be given a definite place in the order of deposition.

The structure which I have described changes toward the surface. It may not have been so well developed in the upper layers, and weathering has obscured the effects. So far have the changes proceeded at this point that the outcrops of rock just above the quarry have to be examined very carefully before any difference in structure can be noted between these rocks and the ordinary firm-textured trap. A wide area of surface surrounding this point plainly shows a survival of the structural differences described, but immediately back of the quarry they are almost gone, though so well developed in the rock beneath. This point should be noted, for in following on the surface the area which was underlain by the lake we find occasionally areas of dense-textured rock, lacking practically all evidence of being different from that which overflowed the arid country, and we should perceive that the presence of surface rock of this nature does not necessarily imply the lack of the characteristic structure beneath. In the areas which I have explored, however, the altered rock has been so frequently found where it has been expected, and where it should have been developed if the lake had the form assumed from the position of the few well-developed exposures which I first noted and on which I based the theory of its existence, that its general form and position can be predicated with fair confidence.

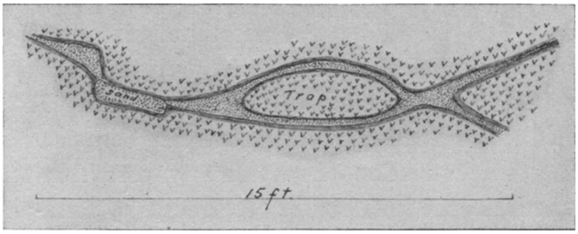


FIG. 10

The features which best survive the effects of weathering are the extremely vesicular or sponge-like facies of the lower layers near the contact, and the smooth, rounded, bowldery forms with brecciated crusts of the upper parts. Of the secondary minerals few survive prolonged weathering, except quartz and prehnite and occasionally calcite, but the irregular cavities from which they have been dissolved have frequently been noted.

The surface areas on which I found these structures in the immediate vicinity are indicated on the map.

Let us now go southward about three miles to an old trap quarry near the Great Notch, formerly worked by Francisco Brothers. Unfortunately no work has been going on here for several years so that the features to which I wish to call especial attention can now be seen at a few points only, though formerly visible over a good part of the quarry. Fig. 10 is from a sketch of the south side of the quarry made in 1902, and Fig. 11 is of the east side made at the same time. The bowlder-forms noted in the West Paterson quarry were well developed and the crystal vugs were also present; but a new feature to be noted is what at first sight appears to be a breccia of sharply defined, angular blocks of sandstone, ranging up to a foot in diameter, lying in the midst of the trap. Their presence in a surface flow of lava might be extremely puzzling until some such occurrence as that shown in Fig. 12 is noted. From a

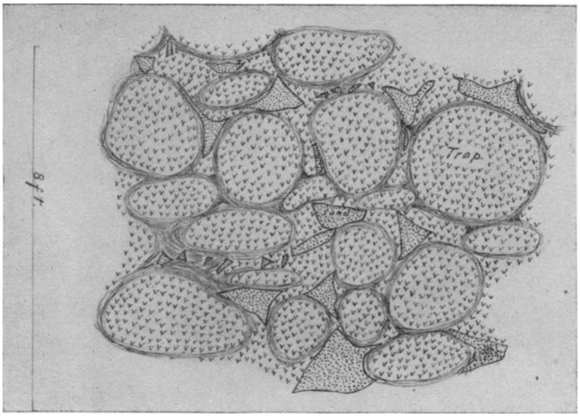
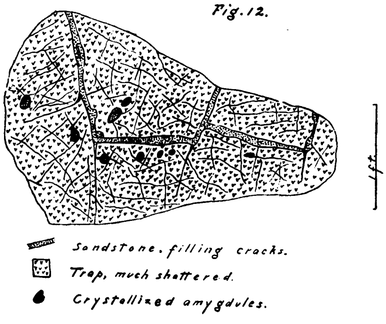


FIG. 11



study of this and of the other occurrences it is seen that the blocks of sandstone are in reality made up of finely divided material caught up from the bottom of the lake and carried to their present position in the form of dust by the blast of steam. Later they were consolidated by the deposition of secondary minerals, but the amount of the latter is so small as not to be perceived at a casual glance. So fine was the dust that it penetrated the most minute crevices and at times its presence can be detected only with a lens. Fig. 13 shows a small block of trap with sand inclusions, drawn in careful detail, and Fig. 14 is another portion of the same block as Fig. 13, showing dust-lined amygdules, later

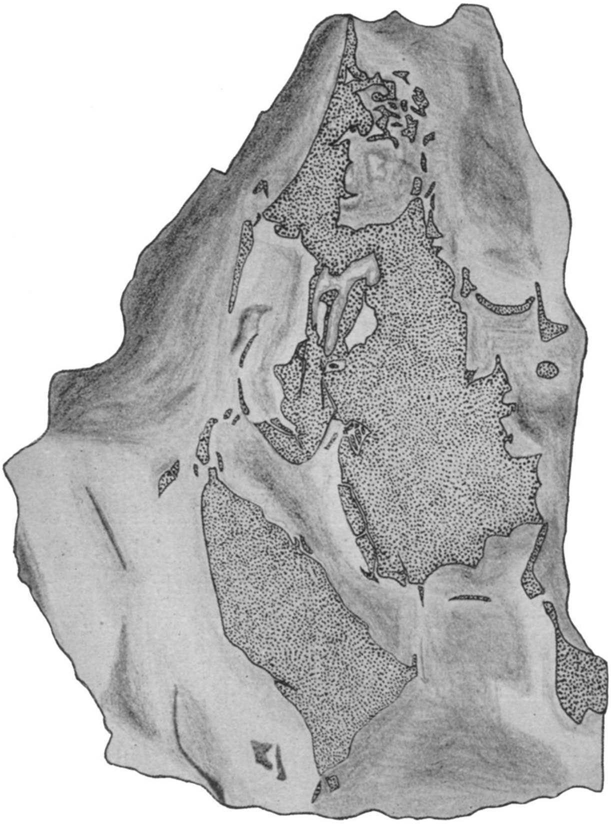


FIG. 13

filled with zeolites. It should be noted that the surface trap at this quarry is of the dense variety for a thickness of several feet and gives no hint of the structure underneath. A short distance west of this point, just below the main line of the N. Y. and Greenwood Lake R. R. is the entrance to a water-supply tunnel, which was driven under the mountain a number of years ago. It entered trap on the western side and came out in the sandstone country on the east, and in its course passed almost directly beneath the Francisco quarry just described, but at a much lower level. At the time that work was in progress much of the material brought out and thrown on the dump was of the characteristic structure which we recognize as being associated with the portion of the lava flow which plunged into the old lake. Glassy crusts, crystal-lined vugs, and sandstone inclusions were all common.

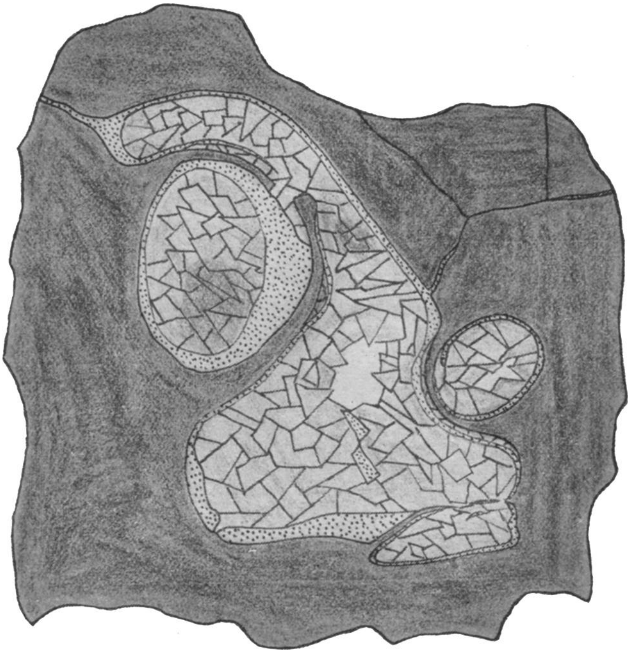


FIG. 14

The two localities described, the one at West Paterson and the other at Great Notch, give us the general line of the lake valley and show us the changes in the trap by which we can recognize its position. I will now take up some of the typical exposures and describe any details which may seem of importance. The most northerly point at which I have found evidence of the existence of the lake is at the corner of Union Ave. and Marion St. in Paterson. There is a small outcrop of trap here, showing bowlder forms and glassy crusts, stained with copper. About half a block south is the site of Hoxsey's quarry, which many years ago was a famous hunting-ground for mineral collectors, and specimens from which are found in cabinets throughout the country. The hill of trap which formed the quarry was leveled off years ago and work was abandoned. A large part of the quarry ground is now built up with houses and nearly all trace of it is gone. When I was familiar with it the form of its structure bore little significance to me, but I remember the general details and believe the structure was almost a duplicate of that now showing in the upper portions of the West Paterson quarry. In one place the floor of the quarry showed calcite-impregnated, amygdular trap, but work was not carried below this. I do not recall the presence of sandstone inclusions, but upon a recent visit to the locality (September, 1907) I was lucky enough to find a little work going on in Kearney St., apparently for a sewer connection, which showed perfectly the crusted bowlder-forms and the vugs and also sandstone inclusions.

Southerly from here is an exposure just east of the reservoir on the hill near the Soldiers' Monument. The outcrop is small but the characteristic features are well developed. This exposure is only a few hundred feet west of the cliffs where Figs. 1 and 2 were sketched and we are now able to appreciate the full significance of the valley shown in these sketches. We see that a river at one time entered the lake at this point, but its valley had been nearly filled and its course almost obliterated until only a shallow depression remained at the time of the trap flow. Its bed was dry, as is shown by the slight degree of vesicularity of the trap at the contact and the close texture above, whereas, over the lake bed the water-soaked muds wrought changes in the trap to a much higher level.

Going a little farther south we come to a small abandoned quarry just across the road from the Water Works Pumping Station. We may note the bowlder-forms here with which we have become familiar and there is another feature of especial interest. The slaggy, wrinkled crust of one of the flows is finely exposed in two or three places. It projects as an inclined shelf, one or two feet wide and fifteen or eighteen feet long, from under later trap, but at only two or three places on this shelf is the structure perfectly developed. The wrinkled surface is shown in Fig. 15. It appears to be a crust one-half to two inches thick, over another flow which also shows a wrinkled surface in one place. Although somewhat weathered the original rock was plainly of a close, glassy texture. No vesicles are visible. The wrinkles are plentiful, forming curved grooves one-fourth to one-half inch deep. The direction of all of them points to a flow northward at this point, and though we must not lay too much stress upon this, a northward flow is perfectly consistent with the shape of the valley. This crust does not of course represent a part of the final surface of the lava flow. It is merely the crust of one of the small sheets, spurted forth under pressure, and soon covered by other portions of the flow. The innumerable bowlder-crusts to be found throughout the area which we are studying are practically the same thing, but in few cases was the wrinkled surface preserved so perfectly as in this example.

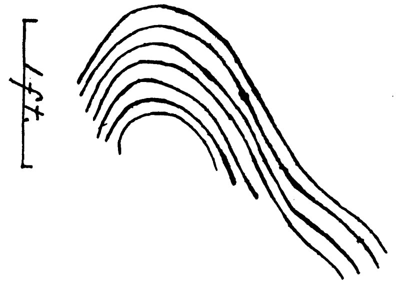


Fig. 15.

At the Falls the rocks on both sides of the river at the brink of the chasm show many irregular vug holes and in places crystals can be seen. We are here, however, far above the base of the sheet and the exposure is not a typical one. Farther south there is an occurrence on the Little Falls turnpike, showing the characteristic structure. The most noteworthy feature is the recurrence here of the wrinkled crust of one of the bowlder masses, showing as a slight projection.

Next comes the West Paterson quarry already described in detail. I have found in this vicinity evidences of the lake valley over a large surface area but have not yet had the opportunity to explore the vicinity in sufficient detail to fix definitely the limits of the area covered by the lake.

Going southward from this point along the mountain road there are positive evidences at many places, as indicated on the map. I have no doubt that with some search other characteristic exposures can be found in this vicinity.

Southwest of the mountain reservoir there is another large area shown. Along the road and in adjacent fields the trap is very vesicular. Plowed fields are filled with the honeycombed fragments and some is plainly in place. A little to the westward the stone walls are built of the crusted bowlders and rock of this structure is also found in place.

South of Great Notch the occurrences in the pipe-line tunnel and in the old quarry of Francisco Brothers have been described. Francisco's new quarry also shows it well at the southern end.

About a half-mile south of Great Notch station is the reservoir of the Newark water department. The work here was done in 1902 and at that time the progress of the work showed the character of the trap underlying the valley. From the gate-house a deep trench was excavated North and South as a foundation for the dam. In this the trap was very porous and vesicular for many hundred feet. From the surface to a depth of twenty feet or so the trench showed bowlder-drift. For probably forty feet below this the trench was in rock, very vesicular, with abundant minerals. Stilbite, chabazite, heulandite, prehnite, calcite, and quartz were recognized. From the gate-house other trenches running east and west showed vesicular trap for several hundred feet. A little to the north the quarry which was opened up for the purpose of obtaining rock for the concrete of the dam shows the bowlder-structure and alongside the road running eastward in front of the dam the rock is honeycombed. These last two exposures are still in evidence, but that in the trenches is now covered with tons of earth and masonry, and the only indications of the rock taken out are the bowlders piled in the road embankment.

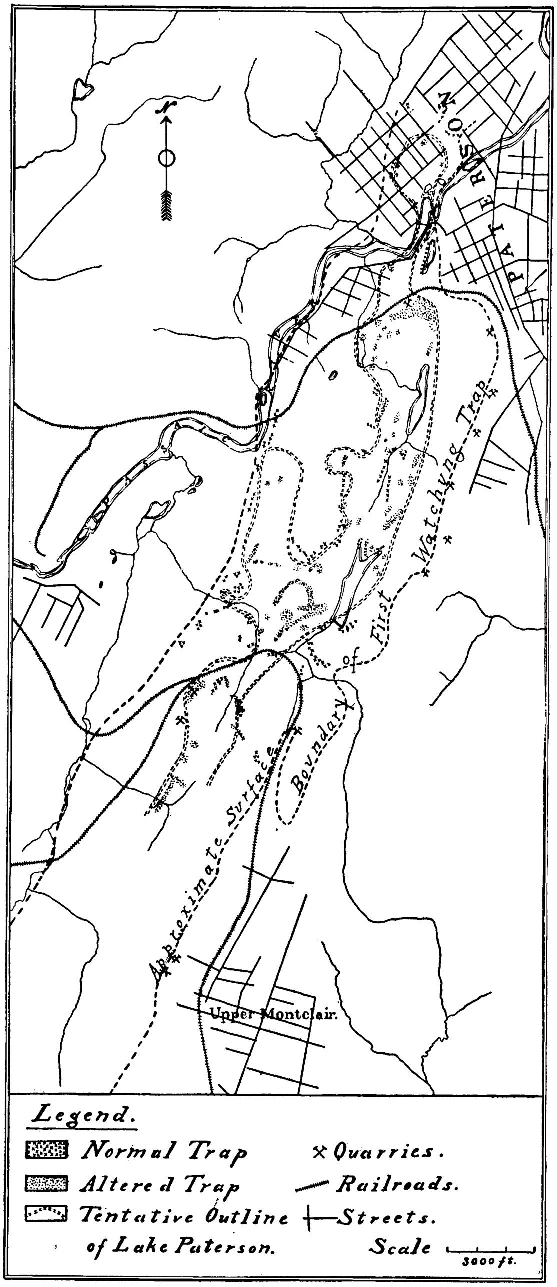
I have not traced the prolongation of the valley south of this point. At Upper Montclair the trap quarry of Osborne and Marsellis shows a set of phenomena which probably has some connection with it, but the exact relations are not certain. The contact of trap and sandstone is seen to be very ragged. Angular blocks of sandstone project upward a distance of eighteen inches or two feet into the trap in many places. Above the contact much of the trap is vesicular, but in places dense trap comes down to the contact. The vesicular trap gives on weathering a brownish, pulverulent, tuff-like material, but I do not think that true tuff is present. Where not weathered it contains many seams and vugs of crystals. The dense trap is sometimes separated quite abruptly from the vesicular form and in other places there is a transition from one to the other.

There was evidently considerable agitation here at the time of the trap flow, but it does not appear to have been so violent as in the cases previously described. The position of this quarry is on the eastern edge of the trap sheet, somewhat removed from the line of direction of the lake valley, so far as determined. I should consider that this marked a spot of marshy ground in the general area of the lake basins, rather than a large body of water. Professor Kemp (in a personal communication) reports the discovery of reptile trails in the shales underlying the trap at this quarry.

A reference to the accompanying map will show many other localities in which typical exposures have been found. In most of these cases the crusted bowlders are the most prominent features to be observed in the structure of the rock. In a few cases I have indicated on the map outcrops of normal, dense trap. These are only shown where they have some significance in defining the limits of the lake area.

FAULTS

An explanation of the appearance of the shales beneath the trap sheet at the West Paterson quarry in the midst of the trap area is required. Along the eastern scarp of the ridge the sandstone series is found to have everywhere a gentle westerly dip, averaging six or seven degrees, as it disappears beneath the trap. Assuming that this dip continued from Garret Rock westward to the quarry, the base of the trap sheet should lie several hundred feet beneath the surface at this point. To explain the reappearance of the sandstone then we must suppose either that there has been a sudden reversal in the direction of the dip or that it has been brought up by faulting. There is no evidence of a reversal of dip and its existence would be contrary to the general monoclinal


N
PATERSON
Approximate Surface Boundary of First Watchung Trap
Upper Montclair.
Legend.
Normal Trap
Altered Trap
Tentative Outline of Lake Paterson.
× Quarries.
Railroads.
Streets.
Scale
3000 ft.

structure of the region. There are, however, excellent reasons for supposing that a series of northerly and southerly faults runs through the country.

A little west of Garret Rock there is a very evident displacement, described and figured by Davis in his paper on the "Triassic Traps and Sandstones," and referred to by Darton,[1] who figures a displacement of about seventy feet, with downthrow on the eastern side, and with this allowance calculates a thickness of seven hundred feet for the trap sheet along this section. On this supposition the underlying shales should lie not less than two hundred feet beneath the surface at the West Paterson quarry. As they are brought up again at this point a displacement of something like two hundred feet by faulting is shown to have occurred, in addition to the seventy-foot throw referred to by Darton. In the quarry itself there are many nearly vertical planes of cleavage, running from top to bottom of the quarry and having a direction nearly north and south. Over much of the country covered by the map there is a prominently developed set of cleavage planes having a general northerly and southerly direction (N. 0 E. to N. 30 E). Frequently where a little quarrying has been done they appear as innumerable sharply defined breaks in the quarry walls. Near the road which runs through the gap of the Great Notch a series of pinnacles on the northern side indicates a faulted structure. This same series of faults continued southward follows the line of valley along which the N. Y. & G. L. R. R. has been built from the station at Montclair Heights northward, and apparently has resulted in the two parallel crests of the ridge here. The faults are well shown in the large quarry near the railroad line in this inner valley and the movements have resulted in the formation of slickensides and gouge matter. There is reason to believe from the evidence at hand that a multitude of displacements of slight throw, and a few well-developed faults of greater throw, all having a northerly and southerly course, have affected the country. The appearance of the underlying lake bottom at West Paterson subtracts two hundred feet from Darton's estimate, and possible displacements to the west of this are likely to reduce the figures still more.

---

[1] *Bulletin 67*, U. S. Geological Survey, "The Relations of the Traps of the Newark System in the New Jersey Region," p. 23.

RÉSUMÉ

We have seen that the series of clastic rocks of the Newark Formation underlying the First Watchung Trap was deposited as surface accumulations in a semi-desert area, mostly under subaerial conditions, in which the wind played an important part. Most of the material from which it was derived is plainly traceable to the old crystallines on the borders of the basin. Either the original floor of the basin on which accumulation began was almost a plain, or accumulation had proceeded to such a degree that minor features of relief had been buried by it, resulting in a surface with only gentle slopes at the period immediately preceding the extrusion of the trap sheet. The usual topographical features of such a surface, in the nature of shallow valleys and stream channels, were present, and we must suppose that the naturally heavier accumulation of detrital material along the bases of the bordering ridges resulted in lines of consequent drainage from the ridges toward a central area of lower-lying ground, which, in the logic of circumstances, would be occupied by a shallow lake or series of lakes. Inasmuch as the drainage on the eastern side of the lakes came from the country lying on the east, we are able to affirm that at least the heavier sediments in the sandstone series on this side of the lakes had their origin in the eastern hills and to point to this section as the original home of the limestone pebbles in the conglomerate beds.

Over such a region a flow of lava poured forth, which accumulated in the low-lying areas occupied by the lakes, and spread out over the sloping ground along the border lines.

When we came to examine the lava itself we saw that it carried in its own mass plain evidences of the structural changes which were produced by the presence of the lakes and of the water-bearing strata beneath. Whereas beyond the borders of the lakes the lava was of a close, firm texture and showed a condition of quiet and tranquillity during the process of cooling and hardening, over the area of lake bottom there was evidence of violent agitation having affected it during the initial flows, and rapid cooling and the production of much glassy material during succeeding flows, followed still later by the crystallizing effects wrought by heated waters and the production of secondary minerals.

By an examination of the territory and a study of the structure of the trap sheet we are able to define approximately the shape of the area covered by the lake or lakes.

I have outlined on the map a tentative boundary. The lake itself seems a sufficiently distinctive feature of the ancient topography to receive a specific name, and I have called it Lake Paterson, from the locality where some of the most typical exposures are to be found.[1]

---

[1] In the *Transactions of the Geological Society of America* for 1897 (Vol. VIII, pp. 59 ff.) Professor B. K. Emerson gives a detailed description of the occurrence of sandstone inclusions in the Connecticut valley traps, which have many points of similarity to those of the New Jersey area. The theory by which he accounts for their presence, however, is, in some features, radically different from that offered here, chiefly in that it is based upon a fundamental conception that the lava was a submarine flow, covering the muddy bottom of a bay. While this may account for the features which he describes in the New England area, I think that the explanation proposed in the preceding pages will better account for the features of the trap sheet and for the relations of trap and sandstones in the New Jersey area.